Magnetically Actuated Propellant Orientation

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In a low-gravity environment, acquisition of vapor-free propellant is complicated by the indeterminate location of bulk liquid with respect to the tank outlet. Proper design of engine feed or propellant transfer systems requires methods to control liquid orientation and an understanding of fluid motion in response to disturbances and imposed accelerations. Traditional approaches for controlling and positioning cryogenic liquids, such as periodic thruster firings and capillary retention devices, exhibit several drawbacks that could be mitigated by employing systems that exploit the inherent paramagnetism of liquid oxygen and diamagnetism of liquid hydrogen. With the advent of lightweight, high-temperature superconductors and high-flux-density, rare-Earth magnets, the use of magnetic fields to control large fluid quantities in microgravity appears feasible, and could enable low-gravity settling, venting, fill, and acquisition without the need for capillary retention systems or propulsive firings. Some of these potential applications are shown in figure 39.

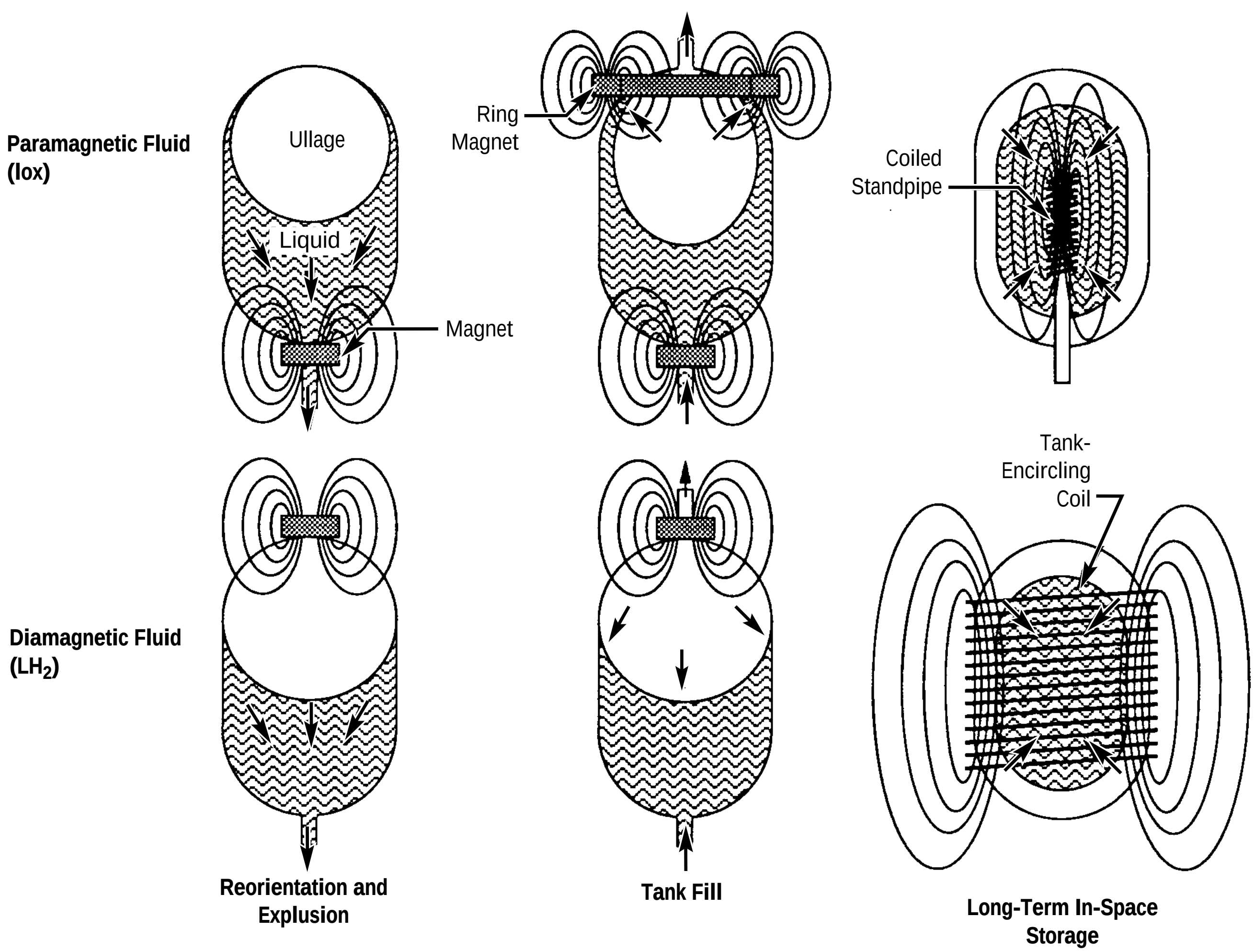

FIGURE 39.—Potential applications of using magnetic fields to control large fluid quantities in microgravity.

This project is currently evaluating the feasibility and practicality of magnetically actuated propellant orientation for spacecraft applications. The scope has been restricted to liquid oxygen primarily because: (1) its control offers the nearest-term application of magnetically actuated propellant orientation technology, (2) the magnetic properties of paramagnetic fluids are well known, and (3) liquid-oxygen behavior has been tested before in low-gravity on a laboratory scale. One of the primary objectives is to determine the range of magnetic field strengths required to perform reorientation and maintain liquid orientation during tank fill and expulsion. This range will provide a basis for evaluating whether these magnetic field requirements fall within the capabilities of current or anticipated superconducting magnet technology.

The project involves low-gravity experiments utilizing the KC–135 aircraft. All experiments employ the subscale hardware shown in figure 40 and a noncryogenic ferrofluid that simulates the paramagnetic behavior of liquid oxygen. The ferrofluid is a commercially available, kerosene-based solution containing a suspension of extremely fine ferrous particles. Several properties of this fluid (i.e., particle density, viscosity, and surface

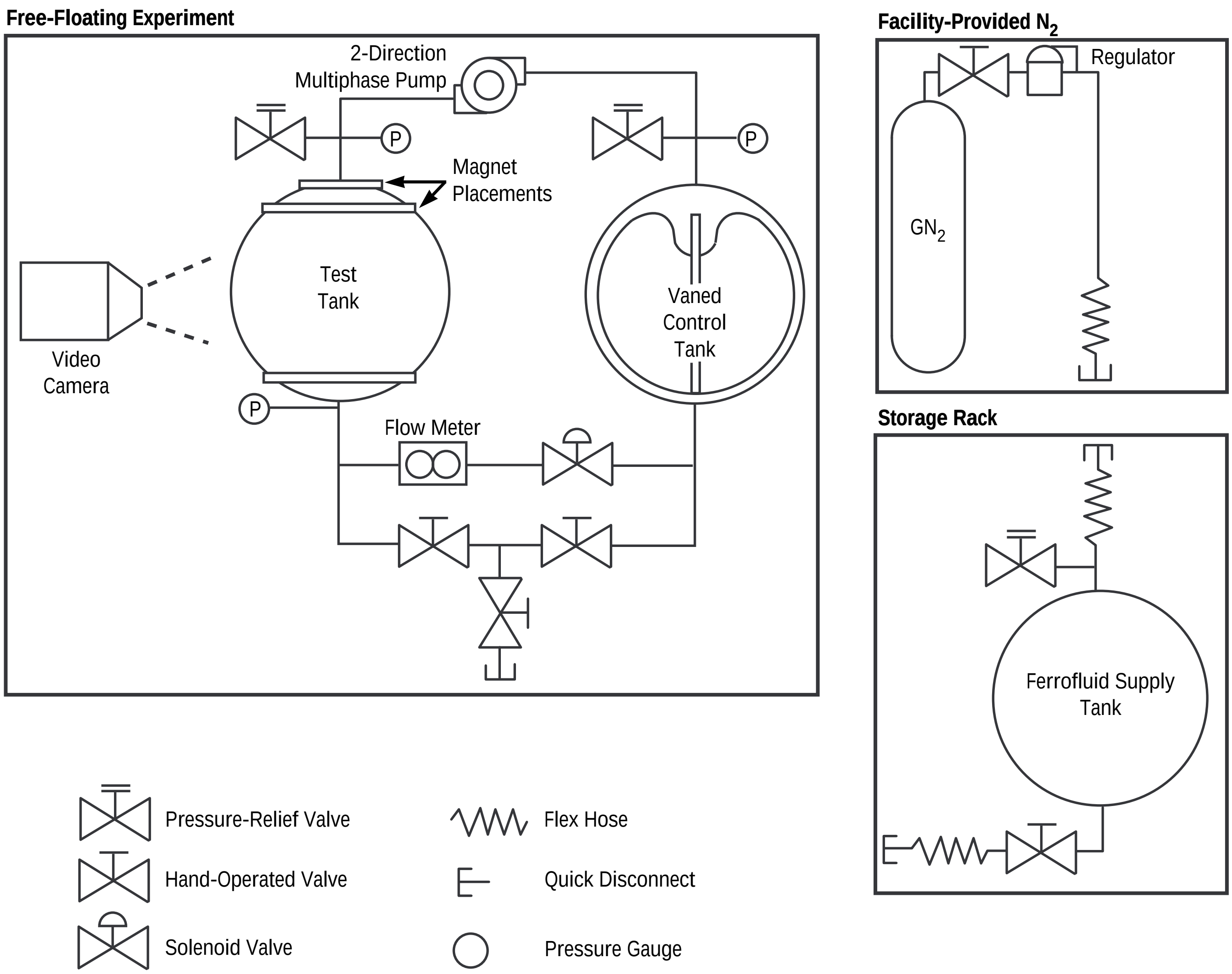

FIGURE 40.—Subscale hardware to be used in KC–135 experiments.

tension), along with tank diameter, flow rates, and magnetic field intensities, are being scaled to model liquid-oxygen behavior in a spacecraft-type application. Design and assembly of the test article is completed, and the facility flew aboard the KC–135 in September 1995. Two other series of tests will be conducted in April and June of 1996.

Scaling analyses have shown that magnets in the size range of 1 to 10 Tesla should be adequate for propellant reorientation in a full-scale liquid-oxygen application. These results, however, are rather limited since the fields can typically assume very complicated geometries, which are difficult to characterize in terms of dimensionless groupings. Consequently, another aspect of this activity is focused on modifying an existing computational fluid dynamic to include the body and surface forces arising from the interactions between the fluid and magnetic field. This will provide a more rigorous means of assessing fluid behavior and will enable the modeling of more complicated field geometries and advanced concepts, e.g., liquid hydrogen. Videotaped recordings of fluid motions taken from the low-gravity tests will be used to validate the revised computational fluid dynamics model.

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